SHORT TERM EFFECTS OF TILLAGE-MULCH PRACTICES UNDER SORGHUM AND SOYBEAN ON ORGANIC CARBON AND EUTROPHIC STATUS OF A DEGRADED ULTISOL IN SOUTHEASTERN NIGERIA [EFECTO DE CORTO PLAZO...

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4 AUTHORS, INCLUDING:

Sunday Obalum
University of Nigeria

Ifeyinwa Uzoh
University of Nigeria

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[EFECTO DE CORTO PLAZO DE LAS PRACTICAS DE LABRANZA Y COBERTERA EN EL CULTIVO DE SORGO Y SOYA SOBRE EL CARBONO ORGÁNICO Y EUTROFICACIÓN DE SUELOS ULTISOLES DEGRADADOS EN EL SURESTE DE NIGERIA]

Sunday E. Obalum[1]*, Ifeyinwa M Okpara[1], Martin E Obi[1], and Toshiyuki Wakatsuki[2]

[1]Department of Soil Science, University of Nigeria, Nsukka 410001, Nsukka
[2]School of Agriculture, Kinki University, Nara 631-8505, Japan
**E-mail: ijewelle@yahoo.com*
**Corresponding author*

SUMMARY

A key indicator of soil quality as organic carbon needs to be enhanced in the highly weathered soils predominant in southeastern Nigeria through appropriate tillage-mulch practices and cropping systems. We subjected a degraded Typic Paleustult (sandy loam) at Nsukka to no-till (NT) and conventional tillage (CT) and bare fallow (B) and mulch cover (M). This was duplicated with one sole-cropped to sorghum and the other to soybean as separate crop treatments during 2006 and 2007 growing seasons. The CT resulted in higher available P ($P_{av)}$ (under soybean) and cation exchange capacity (CEC) (under both crops) than the NT. Mulch gave lower P_{av} under sorghum and vice versa under soybean. Exchangeable Ca was lowered while exchangeable acidity was enhanced with mulch under soybean. Overall, soil organic carbon and exchangeable Mg, Na and acidity were enhanced under soybean relative to sorghum; the reverse was the case for P_{av}. However, the soil's CEC indicated comparable values in both cropping systems. Our results suggest that cropping 'CT with M' soil to soybean could be a promising agronomic combination for enhancing the SOC and fertility status of the soil.

Keywords: tillage system; surface mulch; cropping system; organic carbon; soil fertility; ecology

RESUMEN

El carbono orgánico es un indicador clave de la calidad del suelo que debe ser mejorado en los suelos altamente erosionados del sudeste de Nigeria mediante el empleo de prácticas apropiadas de labranza y cobertera y sistemas de cultivo. Se empleo un suelo típico (limo arcilloso), en Nsukka, a cero labranza (NT) y labranza convencional (CT) y suelo de barbecho descubierto (B) o con cobertura (M). El diseño se empleo en cultivo de sorgo y soya durante dos años consecutivos (2006-2007). Se encontró que CT resultó en valores más altos de P disponible (P_{av}) (con soya) y capacidad de intercambio cationico (CIC) (en ambos cultivos) en comparación con NT. El empleo de cobertura produjo valore más bajos de P_{av} con sorgo y mayores con soya. Ca intercambiable se redujo mientras la acidez mejoró con soya en relación al sorgo mediante el uso de cobertura. En general, el carbono orgánico y Mg intercambiable, Na y acidez mejoraron con soya en relación al sorgo. Lo contrario sucedió con P_{av}. Sin embargo la CIC indicó valores similares en ambos cultivos. Los resultados sugieren que CT con M en soya es una combinación que pudiera ser empleada para mejorar el carbono orgánico y fertilidad del suelo.

Palabras clave: Labranza; cobertura; cultivo; carbón orgánico; suelo; fertilidad; ecología.

INTRODUCTION

The place of soil organic carbon (SOC) as a very influential factor in the monitoring of soil and environmental quality has been widely studied (Reeves, 1997; Wolf and Snyder, 2003; Krull *et al*., 2004; Basamba *et al*., 2006; Lal, 2006; Shukla *et al*., 2006). According to Shukla *et al*. (2006), the conservationists' view of soil quality is centred on sustaining soil resources and protecting the environment. This can be achieved only when the soil is well equipped for its productive and regulatory functions. The SOC is such a key indicator of soil quality that it influences all the indices of soil productivity – including fertility. Chude *et al.* (2004) indicated that the most important crop nutrients in agricultural systems are nitrogen (N), phosphorus (P) and potassium (K). With the exception of fertilizers, soil organic matter (SOM) (from which SOC is usually derived) provides the largest pool of these macronutrients, supplying above 95% of N and 20-75% of P in most soils (Duxbury *et al*., 1989; Baldock and Nelson, 1999). The most important soil chemical property affected by SOC is the cation exchange capacity (CEC) (FAO, 1998), a very important index of soil fertility. Duxbury *et al.* (1989) emphasized the importance of SOM in especially the sandy tropical soils. They noted that most of the CEC in these soils is associated with SOM. Based on a survey of several different soils in the sub-Saharan Africa, Asadu *et al*. (1997) specifically indicated that SOM content could account for about 60% of the effective CEC of the soils. The SOM contents and hence the mineral CEC of these soils are naturally low. Since SOM is the ultimate determinant of soil fertility in most tropical soils (Obatolu and Ibiremo, 1999), the success or failure of crop production in this region relies on the extent of manipulation of the organic matter status of the arable soils.

In southeastern Nigeria, the predominating Ultisols suffer from a combination of 'very' low organic matter content and an unfavourable clay mineralogy dominated by kaolinitic clays. Yet, a common agronomic feature of the region is the continuous cropping of smallholder farms and the associated debilitating effects, without adequate efforts towards replenishment and conservation to ensure sustainability of the soil resources (Ogoke *et al*., 2009). The soil in Nsukka agroecological zone in the region is particularly characterized by very low total exchangeable bases, total exchangeable acidity, and CEC (Asadu, 1990), resulting in an extremely low fertility. Besides, leaching is a major problem in the area (Igwe and Udegbunam, 2008), due to the coarse texture of the mineral soil. This worsens the situation since leaching affects the key soluble macronutrients, including N and P – which are in addition subject to volatilization and fixation respectively. These problems might be of low magnitude if the organic contribution to the soil colloidal system were appreciable. For instance, it has been shown that in such highly weathered and high P-sorbing soils, P maintained in organic pools may be better protected from loss upon fixation than P flowing through inorganic pools (Phiri *et al*., 2001a). In the mean time, practice of organic farming by most of the smallholder farmers in the entire southeastern Nigeria may not be feasible. Regrettably, inorganic fertilizers are not readily accessible either and, where accessible, may not always be affordable to the resource-poor farmers (Ogban *et al*., 2008). This category of farmers thus relies mainly on traditional technology to overcome the above socio-economic constraint, hence the need for continued search for agronomic practices that promote the build-up of SOM and plant nutrients in the region.

Appropriate soil management practices could increase the SOM content to become a source of slow release of nutrients to the soil (Krull *et al*., 2004; Yusuf and Yusuf, 2008). The increasingly popular no-till (NT), a form of conservation tillage that involves leaving residue mulch on the soil surface, has been shown to be a promising alternative to the conventional tillage (CT). This has been attested to in southwestern Nigeria (Lal, 1997; Ndaeyo, 2007; Agbede, 2008; Agbede and Ojeniyi, 2009) and in several other tropical locations (Basamba *et al*., 2006; Saavedra *et al*., 2007; Guimaraes *et al*., 2008; Lopez-Fando and Pardo, 2009). However, cases of measured soil chemical properties indicating comparable values among tillage treatments are still being reported in the tropics (Shemdoe *et al*., 2009), thus suggesting that the NT lacks universal efficacy in restoring soil fertility over the CT in the region. It appears that the rate and magnitude of tillage-induced variations in SOC and the associated soil quality parameters is influenced by cropping system, climate, and soil (Reeves, 1997; Chatterjee and Lal, 2009). With land use as a key determinant of SOC dynamics, use of land for cultivation should aim at determining the effects of common cropping systems, as well as the effects of tillage-mulch practices under the different cropping systems.

Conservation farming practices and better management of cropping systems can improve and maintain the chemical properties of soils (Barber *et al*., 1996; Connolly, 1998), especially those characterized by coarse texture (Buschiazzo *et al*., 1998). Although research on tillage systems has been conducted using the coarse-textured soils in Nsukka agroecological zone for over two decades, most of these studies focused on the physical rather than the chemical properties of the soil (Obi and Nnabude, 1988; Obi, 1989; Mbagwu, 1990; Ahamefule and Mbagwu, 2007; Obalum and Obi, 2010). Moreover, much is not yet known about the effects of cereal- and legume-based cropping systems on soil chemical properties in the zone. Recently, Ogoke *et al*. (2009) advocated agronomic studies on legume species in the cropping systems in southeastern Nigeria, as one of the means of achieving sustainability in the region. There is the need to validate the beneficial effects of NT, as well as the role of mulch, on SOC and in conserving soil fertility and integrity of the ecosystem in this zone. This study was, therefore, carried out at Nsukka to evaluate the effects of soil management practices (NT, CT, bare fallow, and mulch cover) and cropping systems involving sole sorghum [*Sorghum bicolor* (L.) Moench] and sole soybean [*Glycine max* (L.) Merrill] on selected key chemical properties of the soil, after two growing seasons. The objective was to identify the tillage-mulch combination for enhancing SOC and fertility status of the soil, and to determine the relative influence of growing these crops on the selected soil properties.

MATERIALS AND METHODS

Site and soil characteristics

The study was conducted in the 2006 and 2007 cropping seasons at Nsukka (06° 52´ N; 07° 24´ E), with a sub-humid tropical climate. Mean annual total rainfall is about 1600 mm, and is characteristically bimodal in distribution, with peaks during July and October. The entire wet season lasts from April to October, whereas the dry season lasts from November to March. Temperature is uniformly high throughout the year, with mean minimum and maximum annual values of 21°C and 31°C respectively. The soil, which is sandy loam at the top layer, maintains low organic matter status. Steady state infiltration rate ranges from 240 to 750 mm h^{-1} (Obi and Nnabude, 1988). Runoff rarely occurs in the study site not only because of the high infiltration rate (mediated by the coarse soil texture and the poor SOM status), but also due to its gentle slope (only about 1-2%). Having weathered for years, the soil is of low CEC and fertility. The soil belongs to Nkpologu series, and has been classified as Typic Paleustult, using the keys of Soil Survey Staff (2006); or as Ferric Acrisol, according to the Revised Legend of FAO/UNESCO (1988). Dominant plants at the site included such grass species as *Andropogon gayanus, Celosia trigyna, Cynodon nlemfuensis, Emilia sonchifolia, Panicum maximum, Pennisetum polystachion, Oldenlandia corymbosa,* and *Spermacoce verticillata;* leguminous weeds were represented by *Calapagonium mucunoides* and *Mucuna urens*, broad leaf weeds by *Asystasia gangetica.* Prior to the establishment of the experiment in 2006, the site had been under the mixed-species fallow for about 10 years.

Treatments

Land clearing was manually achieved in the site with minimal soil disturbance. In order to ensure good establishment of the crops on this low-fertility soil, a heap of poultry droppings (procured from the same source in each of the two years) was mixed thoroughly and applied uniformly on the soil surface at 5 Mg ha^{-1}. This was allowed to decompose for about two weeks before imposing the tillage-mulch treatments. No inorganic fertilizers were used subsequently. Treatments consisted of factorial combinations of two tillage systems (NT and CT) and two mulch practices [bare fallow (B) and mulch cover (B)]. Manually prepared seedbeds, tilled to depths of about 20 cm, represented CT; clean-weeded flat beds represented NT. The only soil disturbance in the NT occurred during seeding and occasional weeding, using a hand hoe or by hand picking; no herbicides were used. The mulch comprised dry leaves procured from mowed lawns (dominated by *Paspalum notatum*) in the university where the study was conducted, and was applied on the surface at the rate of 5 Mg ha^{-1}.

The factors were laid out in 2^2 split-plot design (wherein the two tillage systems were the main plots and the two mulch practices were the sub-plots). The dimension of each sub-plot was 4.2 m x 2.1 m. Four replications of the four treatments [no-till, bare (NTB); no-till, mulch (NTM); conventional tillage, bare (CTB); conventional tillage, mulch (CTM)] were set up in a randomized complete block design (RCBD). There were two of such layouts (as crop-treatment fields) lying adjacent to each other; one for sorghum and the other for soybean. Late-maturing sorghum (SAMSORG-16) and early-maturing soybean (SAMSOY-2) cultivars were used for the study. The seeds were treated with Apron Star (metalaxyl-M) and were manually sown at the same plant spacing (60 cm x 30 cm), seeding rate (three per hill) and date in each year (3 July in 2006; 7 June in 2007). The seedlings in each field were thinned down to one per stand two weeks after sowing, giving a density of 55 555 plants per hectare at full crop establishment. Owing to the longer time to maturity of the sorghum relative to the soybean cultivar, the latter was harvested earlier than the former in both years (27 Oct. versus 10 Dec. in 2006; 24 Oct. versus 7 Dec in 2007). In both years of the study, the layout of the experiment and the location of the treatment plots remained same.

Analyses

Immediately after the second cropping season, auger topsoil samples were collected, air-dried and passed through a 2-mm sieve before analyses for determination of the selected chemical properties. Mechanical analysis was achieved using the hydrometer method (Gee and Bauder, 1986). Soil pH was measured in soil-water/KCl (1:2.5) suspensions, as described by McLean (1982). The SOC was determined using the modified Walkley-Black wet digestion and combustion method (Nelson and Sommers, 1996). Total soil nitrogen (N_{tot}) was determined by the Kjedahl digestion and distillation method (Bremner and Mulvaney, 1982); available phosphorus (P_{av}) by the Bray 1 Method (Oleson and Sommers, 1982). Determination of the cation exchange capacity (CEC) was by the NH_4OAC displacement method (Rhoades, 1982); exchangeable acidity by the titrimetric method after extraction with 1.0M KCl (McLean, 1982); and exchangeable bases as described by Thomas (1982).

The data were tested for significant differences among the treatments using analysis of variance (ANOVA) for a split plot in RCBD. Where significant, statistically different means were separated using the procedure of Fisher’s least significant difference (F-LSD). Probability level (P) of 0.05 was used as the critical limit for distinguishing the degree of variance between means.

RESULTS AND DISCUSSION

Initial chemical properties of the soil

The chemical properties of the soil–selected for the purpose of this study–at the start of experiment are summarized in Table 1. The soil pH and P_{av} indicated moderate values; whereas percent SOC, percent N_{tot}, and CEC were generally low.

Table 1. Particle size distribution and selected chemical properties of the top-(0-10 cm) soil of the study site at the start of the experiment

Chemical properties and their corresponding values			
Sand (%)	75.2	Exchangeable bases (cmol kg^{-1}): Ca	1.7
Silt (%)	16.0	Mg	1.2
Clay (%)	8.8	Na	0.4
pH (H_2O)	6.6	K	0.1
pH (KCl)	6.1	Exchangeable acidity (cmol kg^{-1})	1.1
SOC (%)	0.50	Cation Exchange Capacity (cmol kg^{-1})	7.0
Total N (%)	0.11	Base saturation (%)	48.6
Available P (mg kg^{-1})	28	Taxonomic class	Ultisol

Organic carbon and total nitrogen

Table 2 shows the effects of the soil management practices and cropping systems on SOC and N_{tot} contents of the topsoil. In comparison with the value (0.50%) at the start of the experiment, there was an overall increase in SOC. Since cultivation generally results in a decline in SOC (Reeves, 1997), the increase in SOC is attributed to the intervening soil management practices. The observation could be due partly to the organic manure (poultry droppings) applied before the tillage operations and sowing in each of the two years (Ano and Agwu, 2005; Agbede and Ojeniyi, 2009). It could also be due partly to the mulch applied to the soil that had been under fallow for some years before the study, as deterioration of the mulch material could add to the soil organic pool and increase the SOC content (Ogban *et al*., 2008).

In either of the sorghum and the soybean fields, main effects of the tillage and mulch factors on SOC and N_{tot} were not significant. Sarno *et al*. (2004) also found no differences in SOC between NT and CT treatments in an acid soil in Indonesia. Although the present soil was not too acidic, the generally low SOC values suggest that the prevailing soil reaction was favourable for accelerated microbial decomposition of organic matter in the soil. Such a condition may not allow for any appreciable tillage-induced differences in SOC. Moreover, the 0-10 cm layer that was sampled in this study probably exceeded the depth limit of the effect of tillage on SOC for the soil. The impact of tillage system on SOC is usually confined within the very top-(0-5 cm) soil (Chatterjee and Lal, 2009; Lopez-Fando and Pardo, 2009). Chatterjee and Lal (2009) observed that beyond this layer, SOC concentrations under NT and CT indicated comparable values most of the time. The non-significant effect of tillage on N_{tot} could be due to the sandy nature of this soil (Buschiazzo *et al*., 1998). Similar observation has earlier been reported in the present site (Anikwe, 2000) and in southwestern Nigeria (Agbede and Ojeniyi, 2009). The present results regarding the effects of the NT and CT on SOC and N_{tot} are consistent with the findings from a five-year study in the semi-arid region of Tanzania (Shemdoe *et al*., 2009).

The non-significant differences in SOC and N_{tot} due to the main effects of mulch practices contrast with higher SOC and N_{tot} values with mulch applied at 10 Mg ha^{-1} for four years in northeastern Nigeria (Chiroma *et al*., 2006). It could be, therefore, that a period of two years was not enough for the effect of the lower mulch rate used in the present study to manifest on the SOC and the N_{tot}. Besides, the nitrogen lock-up frequently associated with mulch (FAO, 1987; Smith, 1993) may have been compensated for by the expected higher volatilization of nitrogen in the bare fallow, hence the non-significant differences in N_{tot}.

The soybean field maintained significantly ($P \leq 0.05$) higher SOC than the sorghum field. This was attributed to increased organic litter associated with leaf fall from the dense and closed canopy of the short and decumbent soybean cultivar used in this study. Furthermore, the prevailing canopy structure ensured low soil temperature, more so with the higher soil moisture content under soybean than under sorghum (Obalum *et al*., 2011). This condition probably led to slow oxidation rate of the decomposed organic litter, hence the enhanced SOC under soybean compared to sorghum. Increase in organic carbon stock of the soil depletes the atmospheric CO_2 level, thus mitigating greenhouse effect and the associated global warming. From ecological perspective, therefore, these results imply safer environment with increasing the frequency of soybean cultivation at the expense of sorghum cultivation.

In spite of the nodulation (nitrogen-fixing) potential of soybean, the N_{tot} under the soybean field indicated statistically same value as that under the sorghum field.

This observation is attributed to the high nitrogen requirement of earthworms (Whalen and Parmelee, 1999), whose population was much higher in the soybean field than in the sorghum field (Obalum and Obi, 2010). Whatever remained of the supposedly enhanced N status of the soybean relative to the sorghum field after depletion by the earthworms must have been depleted further by high volatilization of topsoil N commonly experienced in the tropics.

Soil reaction and available phosphorus

Table 3 shows the topsoil pH and the P_{av} under the various treatments. When compared with the initial value, there was an overall decrease in the soil pH. Soil reaction is one soil property that is easily altered by management. Lowering of the soil pH in this case may be associated with increased biological activity due to the incorporated poultry manure, the accompanying release of CO_2 of which increased the soil acidity. In either of the two crop fields, the tillage factors showed no significant effect on the soil pH. This was attributed to non-application of any chemical fertilizer (Buschiazzo *et al.*, 1998). The present results corroborate Anikwe (2000) that tillage systems had no influence on pH of the soil under study. Similar observation has been reported for an Alfisol in southwestern Nigeria (Agbede and Ojeniyi, 2009), some soils in the semi-arid Tanzania (Shemdoe *et al*., 2009), and some others in the United States (Chatterjee and Lal, 2009). As with the tillage factors, the mulch factors had no appreciable effect on the soil pH. These results suggest that additions of exchangeable bases (particularly Ca^{++} and Mg^{++}) to the soil during decomposition of the mulch material were not appreciable (Chiroma *et al*., 2006).

In the sorghum field, the bare-fallowed plots significantly ($P \leq 0.05$) enhanced P_{av} compared to the mulch-covered plots. Saidou *et al.* (2003) attributed similar observation in a maize field to high P immobilization under surface mulch. In the soybean field, main effects of both the tillage and the mulch factors on P_{av} were significant ($P \leq 0.05$). On one hand, the P_{av} was enhanced under the CT compared to the NT. This result is consistent with Agbede and Ojeniyi (2009), but contrasts with the more commonly reported findings (Ndaeyo, 2007; Saavedra *et al*., 2007; Lopez-Fando and Pardo, 2009). The result just reported suggests that the CT may be a better soil management option in P cycling. Though the reason for this is not very clear, the enhanced the SOC status with the poultry manure applied before tillage operations in each year implies that most of the SOC constituents at the end of the study would be organic rather than inorganic. The fact that SOC is a major source of organic P (Basamba *et al*., 2006) would be expected to be more evident in the soybean field with relatively high SOC content (Table 2). Research has shown that P flowing through organic pools is more readily 'available' compared to inorganic P (Phiri *et al*., 2001a). The P_{av} advantage of the CT over the NT could be due partly to the ineffectuality of the NT in the release of organic P fraction (Basamba *et al*., 2006). Closely related to the above explanation, the results could be due partly to the generally higher moisture contents under the CT than under the NT within the 0-20 cm soil layer of the soybean field throughout the growing seasons (Obalum *et al*., 2011). Increased moist condition of a soil for a reasonable length of time could enhance its P_{av} (Personal communication with C.C. Mba, University of Nigeria, Nsukka). We infer therefore that the P_{av} advantage of the CT over the NT in the soybean field was both SOC- and moisture-mediated.

On the other hand, the mulch-covered plots enhanced P_{av} compared to the bare-fallowed plots under soybean. This was attributed to the prevailing favourable soil moisture status under the mulch-covered compared to the bare-fallowed plots in the soybean field (Obalum *et al*., 2011). Similar to this observation, P_{av} was reported higher with mulch under another legume (cowpea, *Vigna unguiculata*) in this location (Ahamefule and Mbagwu, 2007) and under other crops elsewhere (Sarno *et al*., 2004; Chiroma *et al*., 2006). Tillage x mulch interaction was significant ($P \leq 0.01$) only under soybean, with CTM > NTB > CTB = NTM. This result suggests that the P deficiency common among sandy soils (Klaij and Ntare, 1995) could suitably be coped with using the CTM and the NTB. The lowest P_{av} under the NTM, in spite of the mulch component, is indicative of the degree of the earlier observed poor release of P by the NT treatment in this soil. As opposed to these results, NTM produced the highest P_{av} among a range of tillage-mulch treatments in another agroecological zone in Nigeria (Agbede, 2008; Agbede and Ojeniyi, 2009).

The P_{av} was significantly ($P \leq 0.05$) higher under the sorghum compared to the soybean field. This was attributed to the fact that, in comparison with sorghum, the soybean crop is a high P consumer (Buschiazzo *et al*., 1998; Brady and Weil, 1999). Besides, the 0.1 unit drop in soil pH under the soybean in comparison with the sorghum field may have contributed to the observed lower value of P in the former. Haynes and Mokolobate (2001) showed how availability of P could decrease with decreasing pH. Furthermore, by the relative values of SOC in the two cropping systems (Table 2), SOC-mediated P would be expected to be lower under sorghum than under soybean. The occurrence of higher P_{av} in the soybean system lends credence to the observation by Guo *et al*. (2000) that, irrespective of tillage management, highly weathered soils readily incorporate P from cropping system treatments into the residual P fraction.

Table 2: Soil organic carbon and total nitrogen as influenced by the management practices at the end of the two-year study

	Soil organic carbon (SOC) (%)				Total nitrogen (N_{tot}) (%)			
	Sole sorghum							
Treatments		Mulch practice						
		B	M	Mean		B	M	Mean
Tillage	NT	0.68	0.68	0.68	NT	0.08	0.07	0.07
system	CT	0.61	0.65	0.63	CT	0.07	0.06	0.07
	Mean	0.65	0.67	**0.66**	Mean	0.07	0.07	**0.07**
	†LSD	ns, ns, ns			†LSD	ns, ns, ns		
	Sole soybean							
		B	M	Mean		B	M	Mean
	NT	0.77	0.73	0.75	NT	0.09	0.07	0.08
	CT	0.65	0.75	0.70	CT	0.08	0.09	0.09
	Mean	0.71	0.74	**0.73**	Mean	0.09	0.08	**0.09**
	†LSD	ns, ns, ns			†LSD	ns, ns, ns		
		‡LSD$_{0.05}$		**0.04**		**‡LSD$_{0.05}$**		**ns**
		‡CV (%)		**10.6**		**‡CV (%)**		**21.0**

NT = No-till, CT = Conventional tillage, B = Bare, M = Mulch
†Given for tillage system, mulch practice, and tillage x mulch in that order
‡For comparing the sole sorghum and the sole soybean
ns stands for not significant at $P \leq 0.05$; * and *** denote significance at $P \leq 0.05$ and 0.001 levels of probability, respectively.

Table 3. Soil pH and available phosphorus as influenced by the management practices at the end of the two-year study

	Soil pH in H_2O				Available P (P_{av}) (mg kg^{-1})			
	Sole sorghum							
Treatments		Mulch practice						
		B	M	Mean		B	M	Mean
Tillage	NT	5.8	5.4	5.6	NT	34.3	29.3	31.8
System	CT	5.3	5.1	5.2	CT	31.4	24.4	27.9
	Mean	5.5	5.2	**5.4**	Mean	32.8	26.8	**29.8**
	†LSD	ns, ns, ns			†LSD	ns, 5.4*, ns		
	Sole soybean							
		B	M	Mean		B	M	Mean
	NT	5.3	5.3	5.3	NT	22.4	13.4	19.9
	CT	5.1	5.5	5.3	CT	14.9	30.3	22.6
	Mean	5.2	5.4	**5.3**	Mean	18.6	21.9	**21.3**
	†LSD	ns, ns, ns			†LSD	2.4*, 3.0*, 2.8**		
		‡LSD$_{0.05}$		**ns**		**‡LSD$_{0.05}$**		**4.2**
		‡CV (%)		**5.6**		**‡CV (%)**		**31.2**

NT = No-till, CT = Conventional tillage, B = Bare, M = Mulch
†Given for tillage system, mulch practice, and tillage x mulch in that order
‡For comparing the sole sorghum and the sole soybean
ns stands for not significant at $P \leq 0.05$; * and ** denote significance at $P \leq 0.05$ and 0.01 levels of probability respectively.

Exchangeable bases and acidity

The tillage systems had no influence on any of the exchangeable bases and acidity in either of the two cropping systems (Table 4). Similar results have been reported elsewhere in the tropics for Ca^{++} and K^{+} (Agbede and Ojeniyi, 2009) and for all the exchangeable bases (Shemdoe *et al*., 2009). The Ca^{++} was significantly ($P \leq 0.05$) lower whereas exchangeable acidity was significantly ($P \leq 0.01$) higher, under the mulch-covered plots than the bare-fallowed plots of the soybean field (Table 4). It could be that the present mulch rate could not enhance the Ca^{++} within the duration of the study. Mulch applied at a higher rate for four years was reported to enhance the exchangeable bases in another agroecological zone in northeast Nigeria (Chiroma *et al*., 2006). There was however significant ($P \leq 0.05$) tillage x mulch interaction in the present study, and this indicated that the CTB was superior to the NTB in enhancing Ca availability in this soil. Similar observation in a Brazilian Oxisol was attributed to increased pore continuity and associated pronounced nutrient leaching under the NT relative to the CT (Lilienfein *et al*., 2000).

Each of the exchangeable Mg, Na and acidity was significantly ($P \leq 0.05$) enhanced in the soybean compared to the sorghum field. The exchangeable Mg increased by over three times under the soybean relative to the sorghum for which was comparable to the value at the start of the study. Perhaps, the initially applied poultry manure boosted the status of Mg^{++} in the soil. The relative abundance of Mg^{++} in the two crop fields at the end of the study suggests that soybean nutrition of Mg is low compared to that of sorghum. Another plausible mechanism was inhibition of Mg uptake by soybean but not sorghum. Legget and Gilbert (1969) showed how Mg uptake by soybean could be inhibited in a soil solution containing both Ca and K. Since these two cations (Ca^{++} and K^{+}) were present in equal amounts under both crops (Table 4), it could be that Mg^{++} was sparingly taken up by the soybean crop, hence the observed higher Mg^{++} under soybean than under sorghum. There was an appreciable increase in exchangeable acidity (which was dominated by H^{+}, with Al^{3+} occurring in traces) in the cropping systems over the baseline value. In such highly weathered mineral soils with H^{+} as the dominant acidic cation, increases in the exchangeable acidity would be expected due to the overall decrease in soil pH relative to the value at the start of the study (Brady and Weil, 1999). Similar increases in exchangeable acidity accompanying a decrease in soil pH have been reported by Chiroma *et al.* (2006) and Ogban *et al*. (2008) in northeastern and southeastern Nigeria, respectively.

Cation exchange capacity and base saturation

Table 5 shows that there was relative improvement in the CEC of the soil with the CT under both cropping systems. Similar observation has been reported elsewhere (Limousin and Tessier, 2007). The CEC was significantly ($P \leq 0.01$) higher while base saturation (BS) was significantly ($P \leq 0.05$) lower, under the bare-fallow plots than under the mulch-covered plots of the sorghum field. Sarno *et al*. (2004) showed that a bare soil could result in more clay fraction, in comparison with a mulch-covered soil. This might have been the case here, since clay is an important contributor to the CEC of soils.

Both the CEC and the BS indicated statistically similar values under both crops. This is in spite of the low SOC content in the sorghum compared to the soybean field (Table 2). These results indicate that, although SOM is a major determinant of CEC in the highly weathered Ultisols, the relationship between SOM and CEC in such soils may not always be linear. The CEC is almost entirely dependent on not just the amount, but also on the type of organic matter (FAO, 1998). Perhaps, the particulate organic matter fraction that is more sensitive to management than total SOM (Cambardella *et al*., 2001; Zagal *et al*., 2009) was not affected by the cropping systems. This fraction is often considered the most important SOM fraction in soil nutrient dynamics and in providing nutrients to plants (Phiri *et al*., 2001b; Wolf and Snyder, 2003; Basamba *et al*., 2006). For this labile SOM fraction, a period of two years was probably not enough for the effects of the cropping systems to manifest. Freixo *et al*. (2002) and Bessam and Mrabet (2003) found that cropping legumes on highly weathered NT soils produced this high quality SOM fraction only in the long term.

CONCLUSIONS

The nutrient-supplying ability of the soil (CEC) was higher under the CT compared to the NT in both cropping systems. Effects of the tillage-mulch practices on P availability were dependent on crop grown. Generally, the cropping systems had more pronounced influence on SOC and some other fertility parameters of the soil than did the tillage-mulch practices. In terms of SOC and some exchangeable nutrient elements, the highly weathered and nutrient-poor soil tended to be more responsive to soybean than to sorghum. Such benefits associated with soybean relative to sorghum sole-cropping were most evident with the CTM. However, the whole SOC advantage of the soybean over the sorghum field did not confer higher CEC nor result in better nutrient status and higher soil fertility in the former than in the latter. Should any future studies yield such results, there may be need to ascertain the status of particulate organic matter before any reliable inference could be drawn. The potential of fostering sustainable crop production and ecological balance through enhanced SOC pools with cropping the CTM to soybean in this and similar agroecological zones should be validated through longer term trials.

Table 4. Exchangeable bases and acidity of the top-(0-10 cm) soil under the management practices at the end of the two-year study

Exchangeable bases															
	Ca^{++}			Mg^{++}			K^{+}			Na^{+}			Exchangeable acidity		
…… (cmol kg^{-1})……															
Sole sorghum															
	B	M	Mean	B	M	Mean	B	M	Mean	B	M	Mean	B	M	Mean
NT	1.5	1.8	1.7	0.9	1.2	1.1	0.10	0.12	0.11	0.35	0.39	0.37	1.3	1.4	1.4
CT	2.1	1.7	1.9	0.8	1.4	1.1	0.10	0.12	0.11	0.35	0.39	0.37	1.3	1.5	1.4
Mean	1.8	1.8	**1.8**	0.9	1.3	**1.1**	0.10	0.12	**0.11**	0.35	0.39	**0.37**	1.3	1.5	**1.4**
†LSD	ns, ns, 0.5*			ns, ns, ns			ns, ns, ns			ns, ns, ns			ns, ns, ns		
Sole soybean															
	B	M	Mean	B	M	Mean	B	M	Mean	B	M	Mean	B	M	Mean
NT	1.5	1.5	1.5	3.0	3.5	3.3	0.09	0.13	0.11	0.39	0.35	0.37	1.3	1.8	1.6
CT	2.2	1.5	1.9	3.5	3.5	3.5	0.10	0.12	0.11	0.41	0.37	0.39	1.6	1.8	1.7
Mean	1.9	1.5	**1.7**	3.3	3.5	**3.4**	0.10	0.12	**0.11**	0.40	0.36	**0.38**	1.5	1.8	**1.7**
†LSD	ns, 0.3*, 0.5*			ns, ns, ns			ns, ns, ns			ns, ns, ns			ns, 0.2**, ns		
	‡$LSD_{0.05}$		**ns**	**‡$LSD_{0.05}$**		**0.2**	**‡$LSD_{0.05}$**		**ns**	**‡$LSD_{0.05}$**		**0.01**	**‡$LSD_{0.05}$**		**0.1**
	‡CV(%)		**21.5**	**‡CV(%)**		**28.7**	**‡CV (%)**		**16.5**	**‡CV (%)**		**6.6**	**‡CV(%)**		**16.1**

NT = No-till, CT = Conventional tillage, B = Bare, M = Mulch
†Given for tillage system, mulch practice, and tillage x mulch in that order
‡For comparing the sole sorghum and the sole soybean
ns stands for not significant at $P \leq 0.05$; * and ** denote significance at $P \leq 0.05$ and 0.01 levels of probability respectively.

Table 5. Cation exchange capacity and base saturation of the top-(0-10 cm) soil at the end of the two-year study

		Cation exchange capacity (CEC) (cmol kg^{-1})				Base saturation (BS) (%)		
	Sole sorghum							
Treatments		Mulch practice						
		B	M	Mean		B	M	Mean
Tillage	NT	6.4	4.7	5.6	NT	44.4	73.9	59.2
System	CT	8.6	5.3	6.9	CT	39.0	67.9	53.4
	Mean	7.5	5.0	**6.3**	Mean	41.7	70.9	**56.3**
	†LSD	1.1*, 0.9**, ns			†LSD	ns, 15.0* , ns		
	Sole soybean							
		B	M	Mean		B	M	Mean
	NT	6.7	5.3	6.0	NT	45.1	59.5	52.3
	CT	6.4	8.3	7.4	CT	59.0	37.3	48.2
	Mean	6.6	6.8	**6.7**	Mean	52.1	48.4	**50.2**
	†LSD	0.27**, ns, ns			†LSD	ns, ns, ns		
		‡$LSD_{0.05}$		**ns**		**‡$LSD_{0.05}$**		**ns**
		‡CV		**21.9%**		**‡CV**		**28.2%**

NT = No-till, CT = Conventional tillage, B = Bare, M = Mulch
†Given for tillage system, mulch practice, and tillage x mulch in that order
‡For comparing the sole sorghum and the sole soybean
ns stands for not significant at $P \leq 0.05$; * and ** denote significance at $P \leq 0.05$ and 0.01 levels of probability respectively

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